NUCLEAR ENERGY RESEARCH INITIATIVE

Gradient Meshed and Toughened SOEC Composite Seal with Self-Healing Capabilities

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Research Objectives

Hydrogen generation through high-temperature electrolysis, using nuclear heat from advanced gas-cooled or liquid-metal-cooled reactors, will play a significant role in the Nuclear Hydrogen Initiative. High-temperature steam electrolysis enhances the efficiency of hydrogen production by adding substantial external heat, which reduces electricity consumption. Very-high-temperature advanced reactors can provide the necessary heat to enable high-efficiency hydrogen production without the use of carbon fuels.

However, current solid-oxide electrolyzer cell (SOEC) seals hinder this promising technology due to a mismatch in thermal expansion coefficients that causes seal cracking and gas leakage. The objective of this project is to match the SOEC seal expansion coefficient with other cell components by using a glass-filled, titanium-nickel-hafnium (TiNiHf) high-temperature shape memory alloy (SMA) mesh to create a transition gradient. This novel seal design will enable long-term SOEC operation by providing mechanisms for glass matrix toughening and crack self-healing.

Researchers will conduct experiments to approximately 500 hours duration and extrapolate the results to 40,000 hours or more in order to predict long-term cell performance. They will assess overall stability, performance, and cost of the seal using actual SOECs and cost models.

Research Progress

This project will develop a novel composite seal by integrating 3-D printed shape memory alloy wires into a glass matrix. Using the unique structure of the SMA wire mesh, researchers will create a thermal expansion gradient across the seal thickness, provide self-healing of cracks by the alloy shape memory effect, and reduce thermal stresses by SMA phase transformation toughening. They are using TiNiHf as the SMA material and SLABS—an aluminosilicate-based compound (SrO-La_2O_3-Al_2O_3-B_2O_3-SiO_2)—for the glass matrix.

Researchers have synthesized TiNiHf and successfully achieved a shape memory effect. Differential scanning calorimetry and microscopy have shown that the alloy has shape memory phase changes between 180 and 250°C. After the alloy solidifies, a homogenization heat treatment is necessary in order to visualize the shape memory effect. Using scanning electron microscope (SEM), researchers found evidence of incipient melting during homogenization, which they believe is due to a slightly low nickel (Ni) concentration in the SMA alloy. Work is underway to increase the Ni content.

Researchers synthesized several batches of SLABS glass to make cylindrical dilatometry samples and milled them into powders. The dilatometry test shows the overall coefficient of thermal expansion (CTE) is 13.9 x 10^{-6}/°C. However, it changes significantly with temperature, as indicated in Table 1. These data pinpoint regions of different CTEs under the same SOEC thermal cycle within the same material.

Temperature Range	CTE
40–500°C	7.02 x 10^{-6}/°C
500–700°C	32.0 x 10^{-6}/°C
700–800°C	21.4 x10^{-6}/°C
Overall	13.9 x 10^{-6}/°C

Table 1. Dilatometry test results of SLABS samples.

The most problematic region for the studied SLABS glass system is 40-500°C—the typical heating and cooling region. Researchers have demonstrated that the proposed SLABS glass has much higher CTE than the seal glasses currently used in SOEC research. This glass shows great potential for mitigating the thermal expansion mismatch issues that are hindering the long operational lifetime of SOECs.

The TiNiHf shape memory effect overlaps with this problematic low CTE region of the SLABS glass. This supports the assumption that gradient transition, phase transformation toughening, and SMA self-healing can be utilized to mitigate/eliminate the seal problem.

Planned Activities

Researchers plan to perform the following tasks over the next fiscal year:

- Continue to study TiNiHf high-temperature SMA and SrO-La_2O_3-Al_2O_3-B_2O_3-SiO_2 (SLABS) glass seal systems and tailor their compositions to produce complementary thermal behaviors during SOEC operation
- Use three-dimensional printing to build a TiNiHf mesh for the seal on the interconnect side and provide gradient thermal expansion coefficients from the interconnect to the electrolyte across the seal thickness to greatly reduce thermal stress
- Fill SLABS glass into the meshed TiNiHf structure, transitioning into pure glass on the electrolyte side, to make seals with transformation toughening and crack self-healing capabilities
- Conduct comprehensive seal testing to demonstrate smooth thermal expansion coefficient transition, cracking resistance, and crack self-healing capabilities of the new composite seal
- Conduct field testing using actual SOEC seal configurations and model the process to optimize cost and opportunities